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Maximizing Signal Quality for One-Dimensional Cells in Mobile Communications

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ABSTRACT: In this work, the cellular network performance based on other cell interference predictions is presented. It presents a mathematical model of co-channel interference analysis in hexagonal and linear cell shapes through a log-distance propagation model to investigate the effect of path loss exponent value on the received signal quality of the downlink. Simulation results obtained show that as the power exponent value increase, the interfering signals attenuation is increased resulting in received signal quality improvement. The signal-to-interference ratio (SIR) received by subscribers close to the cell edge will be less due to the contribution of the near-interfering cells especially when multiple layers of interfering cells are considered. The simulations confirmed that the impact of multi-tiers of interfering cells cannot be ignored in systems of small cluster size as they may contribute to system performance degradation.

Keywords: Interference Analysis, Path loss Modeling, Cellular Networks, Number of interfering cell tiers, Linear cells.

1. INTRODUCTION

The principle of cellular mobile communication networks is the utilization of limited radio bandwidth to accommodate a large number of subscribers by means of frequency reuse technique [1]. The scarcity of available frequency bands has led to the necessity of reusing the same frequency channel for different spatial cells to face the increasing demand for cellular communication services. When the same radio channels are utilized again in the range of short distances, it introduces co-channel interference that can be considered as the major limiting factor affecting the cellular network performance as the interference reduction results in capacity extension [2–5]. The frequency reuse technique must be used efficiently to provide the required quality of service for each mobile subscriber and minimize the co-channel interference caused by other subscribers from other distant links operating at the same channel. The quality of service of any wireless communication network is measured by the signal-to-interference ratio (SIR); therefore, the concept of reuse distance has been introduced [6–8]. The propagation channel models are fundamental tools used to estimate signal attenuation and frequency reuse distance in wireless communication systems. These models capture the effects of various factors such as distance, frequency, and environmental conditions on signal propagation. The selection of an appropriate propagation channel model directly impacts the accuracy of signal quality predictions, coverage area, and frequency plan setting [5, 9–12]. In [5, 13], calculations of interference from co-cells and adjacent channel in 2G and 3G base stations of cellular communication systems operating in urban n environment is presented. The system capacity in terms of active users was estimated. In [14], the reduction of co-channel interference with the use of sectored antennas was analyzed. The first tier of interfering cells was considered while the interference from the subsequent tiers was neglected. The effect

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of adjacent channel interference on communication range and outage probability for intelligent transportation systems (ITS) was studied in [15–17]. The bit error rate (BER) was calculated in different scenarios. An analytic approach was applied in [18] to investigate the adjacent channel interference in underground trains that use Long Term Evolution-Metro (LTE-M), for train control. The study presented a new method to determine the required separation distance for LTE-M systems to avoid interference. This paper focuses on determining the exact Signal to Interference Ratio (SIR) experienced by mobile stations at various distances from their serving base station. The calculation will be carried out for hexagonal and linear shape cellular systems with consideration of many tiers of interfering cells. Section 2 of this paper presents the frequency reuse and co-channel interference concepts. Section 3 will describe two types of cluster formation and the SIR calculation method. Section 4 will provide the results of simulations and comparisons. The paper will be concluded with results discussion in Section 5.

2. CO-CHANNEL INTERFERENCE FORMULATION

The signal power to interference power ratio (SIR) is one of the physical measures of RF channel quality. If the measured SIR falls below a certain threshold, the mobile should be in the coverage region of another surrounding cell and a cell handoff should be performed. The SIR ratio depends on the number of interfering cells (K_o), according to the formula

$$\frac{S}{I} = \frac{S}{\sum_{k=1}^{K} I_k} \tag{1}$$

Where S is the power of the signal received by the mobile unit from its serving base station, I_k is the mean interference power caused by the k-th interfering cell, and K is the interfering cell number in the first tire surrounding the home cell. The log-distance propagation model is a distance-dependent model. Signal transmission is subject to an inverse path-loss propagation exponent. The signal power S received at the receive antenna of the mobile placed at distance R from the serving base station is directly proportional to the base station transmitted power, and inversely proportional to $(R)^g$, where (g) is the path loss exponent value. The mean interference power from the transmit antenna of the surrounding interfering cells is proportional to the transmitted power and inversely proportional to (D^g), where D is the distance between the home cell and any one of the co-channel cells at the first tier.

$$S \propto \frac{P_t}{R^{\gamma}}, \quad I \propto \frac{P_t}{D^{\gamma}}$$

Assuming that all base stations emit signals with equal powers through omnidirectional antennas, the signal to co-channel interference ratio at the mobile unit located at the central cell can be given as [7–9].

$$SIR = \frac{S}{\sum_{k=1}^{K} I_k} = \frac{R_c^{-\gamma}}{\sum_{k=1}^{K} (D_k)^{-\gamma}} = \frac{1}{\sum_{k=1}^{K} \left(\frac{D_k}{R_c}\right)^{-\gamma}} \tag{2}$$

Where D_k is the distance between the centered cell and the k-th interfering cell centers at the first tire (reuse distance), R_c is the cell radius and g is the path loss exponent value that depends upon the environment nature and lies in the range between 2 and 6 [7–9]. In this paper, base stations are assumed to be center excited, and the frequency band is distributed uniformly among the covered cells, and these channels of any cell are reused in other cells spaced a distance D away from the home cell. The reuse distance D, and cell radius R_c are related by the relation [9]:

$$\frac{D}{R_c} = Q \tag{3}$$

Where Q is the reuse factor or co-channel reduction factor.

3. HEXAGONAL AND LINEAR CELLS CONFIGURATIONS

3.1 FOR HEXAGONAL CELL TOPOLOGIES

In hexagonal cell topology, a home cell and co-channel cells in surrounding tiers are considered. The first tier has only six interfering cells that located at the reuse distance D from the center of the home cell, and twelve interfering cells at the second tire at 2D from the center of the home cell as illustrated in Figure 1. In hexagonal systems, the reuse factor and the cluster size N (number of cells in a cluster) are related by the relation:

$$Q = \frac{D}{R_c} = \sqrt{3N} \tag{3}$$

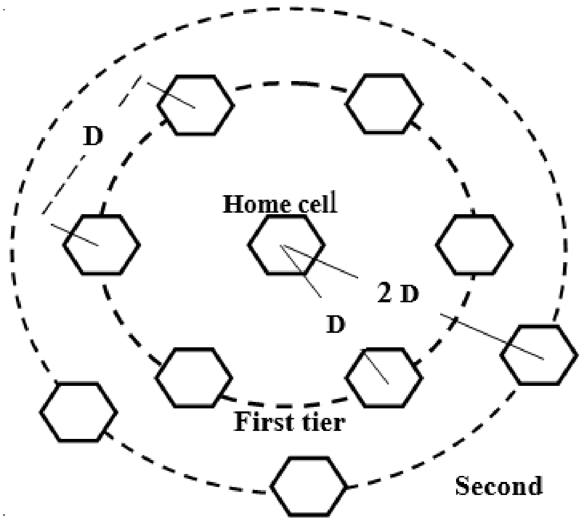

FIGURE 1. **Interfering cells in hexagonal configuration**

Assuming that the mobile unit at the home cell is located at the distance x from its serving base station, the SIR result due to the impact of **the first tier** of interfering cells will be expressed as:

$$SIR = \frac{R_c^{-\gamma}}{2(D-x)^{-\gamma} + 2(D+x)^{-\gamma} + 2D^{-\gamma}} \quad (3)$$

Dividing by R_c, equation 3 can be rewritten as

$$\text{SIR} = \frac{(R_c/R_c)^{-\gamma}}{2\left(\frac{D}{R_c} - \frac{x}{R_c}\right)^{-\gamma} + 2\left(\frac{D}{R_c} + \frac{x}{R_c}\right)^{-\gamma} + 2\left(\frac{D}{R_c}\right)^{-\gamma}} \quad (4)$$

The equation can be written in terms of the co-channel reduction factor (Q), as

$$SIR = \frac{1}{2\left(Q - \frac{x}{R_c}\right)^{-\gamma} + 2\left(Q + \frac{x}{R_c}\right)^{-\gamma} + 2(Q)^{-\gamma}} \quad (5)$$

When the user is located at the center of the home cell (x=0) where x is the distance between the subscriber unit and its serving base station, then all distances between interfering base stations and the mobile station at the home cell center are equal ($D_k = D_1 = D_2 = D_3 = D_4 = D_5 = D_6$), and the average SIR can be given as:

$$SIR = \frac{1}{2(Q)^{-\gamma} + 2(Q)^{-\gamma} + 2(Q)^{-\gamma}} = \frac{1}{6(Q)^{-\gamma}} \quad (6)$$

For different mobile station locations (x) that can be expressed in terms of R_c, the SIR can be easily calculated. As an example, where the mobile station is located at x=0.25 R_c, the SIR will be:

$$SIR = \frac{1}{2\left(Q - \frac{0.25R_c}{R_c}\right)^{-\gamma} + 2\left(Q + \frac{0.25R_c}{R_c}\right)^{-\gamma} + 2(Q)^{-\gamma}}$$

$$SIR = \frac{1}{2(Q-0.25)^{-\gamma} + 2(Q+0.25)^{-\gamma} + 2(Q)^{-\gamma}}$$

For the worst case, the subscriber unit will be located at the cell border (x= R_c) that results in minimum SIR as shown in Figure 2.

$$SIR = \frac{1}{2(Q-1)^{-\gamma} + 2(Q+1)^{-\gamma} + 2(Q)^{-\gamma}} \quad (7)$$

As the reuse distance between the home cell and any of interfering cells in the second tier is equal to 2D, the co-channel reduction factor Q will be replaced by (2Q) in equation (5) when considering the second tier, and (3Q) when considering the third tier of interfering cells.

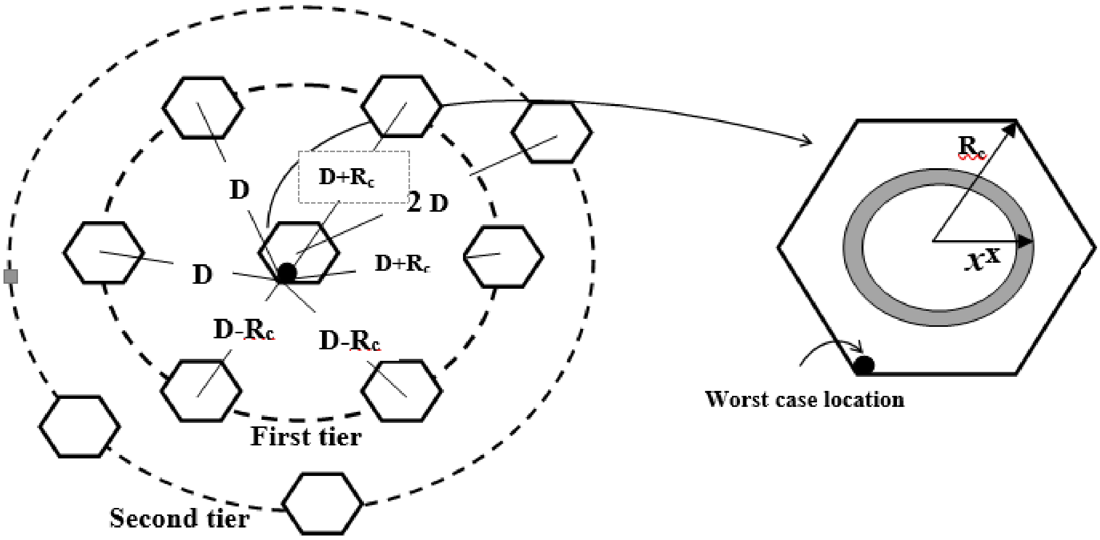

FIGURE 2. Mobile station with worst case location

3.2 FOR LINEAR CELL TOPOLOGIES

Sometimes, non-hexagonal cell shapes are made such as linear one-dimensional microcells consisting of concatenated segments (cells) of a highway or rural road. These one-dimensional cells are usually used to cover long stretches of highways in unpopulated or rural regions. As shown in Figure 3, each microcell (segment) has a length of $2R_C$ where R_C is the cell radius, and base stations are spaced every $2R_C$. It can be noticed that the distance between the centered cell and any co-cell centers in the first tire, D is equal to $4R_C$ where the cluster size is 2, $6R_C$ where the cluster size is 3, $8R_C$ where the cluster size is 4, Therefore, it can be concluded that the ratio D/R_c can be expressed as:

$$\frac{D}{R_c} = Q = 2N \tag{8}$$

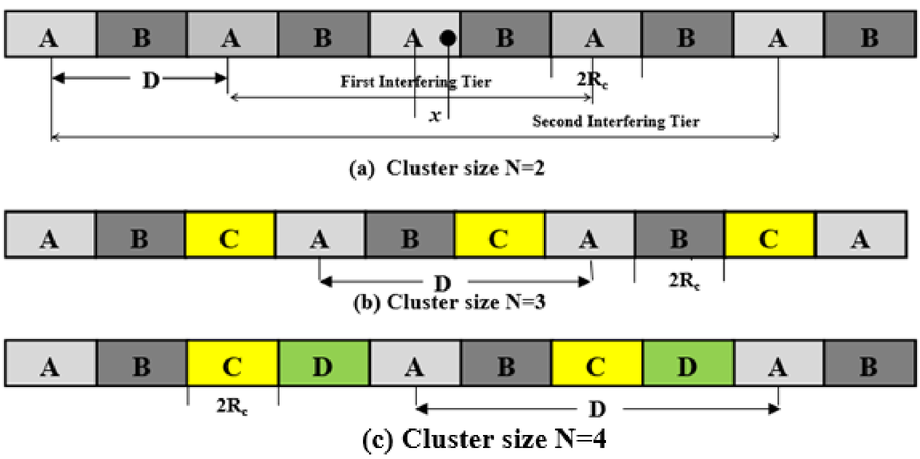

FIGURE 3. Highwaycells topology

When the mobile unit at the home cell (A) in Figure 3-a is located at the distance x from the serving base station, the SIR resulted due to the effect of first interfering cells tier, and the impact of the first and second tier of interfering cells can be expressed by the following equations:

$$SIR = \frac{x^{-\gamma}}{(4R_c + x)^{-\gamma} + (4R_c - x)^{-\gamma}} \tag{9}$$

$$SIR = \frac{x^{-\gamma}}{(4R_c + x)^{-\gamma} + (4R_c - x)^{-\gamma} + (8R_c + x)^{-\gamma} + (8R_c - x)^{-\gamma}} \tag{10}$$

4. SIMULATION RESULTS AND DISCUSSION

Simulations were performed to compute the variation of the SIR at the mobile station at different distances from the cell center to the radius (x=R_c), within the home cell coverage area. Simulations were obtained considering the impact of the many tiers of neighboring interfering cells. The impacts of path loss exponent and cluster size have been studied in both hexagonal and linear cell systems. From Figure (4), it can be noticed that as the cluster size increased in linear cell topology, the SIR at the mobile unit increased. For a cluster of three cells (N=3), the SIR is about 12.189dB, while it is equal to 14.847dB for (N=4) where the mobile unit is located at the cell edge (x=R_C). This occurs because as the cluster size increased the reuse distance is also increased, and the effect of the interfering cells is decreased. Furthermore, the figure shows the SIR variation with distance. The SIR decreases as the distance between the mobile unit and its serving base station is increased, especially for small cluster sizes. At the closest location, the serving base station provides the strongest signal power due to small distance attenuation. Figure (5) shows the effect of three tiers of interfering cells surrounding the home cell. It can be concluded that for smaller cluster sizes, the SIR is less when considering three tiers, and still the SIR is less than the case of one interfering tier because the number of interfering cells will be increased in multi tiers.

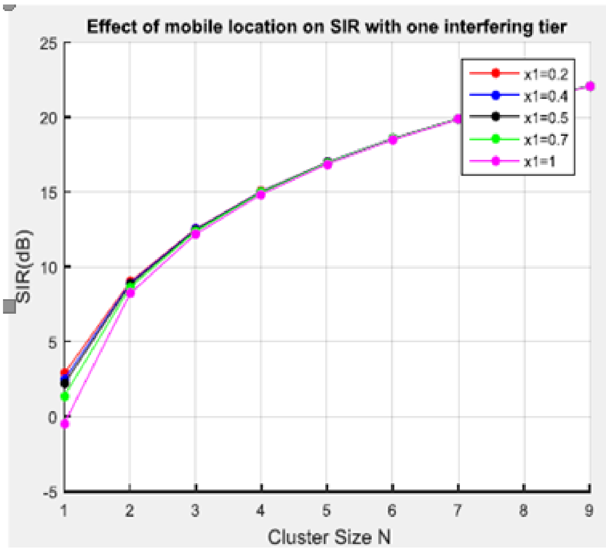

FIGURE 4. Effect of cluster size on SIR

The effect of path loss exponent value is illustrated in figure (6). It can be seen that for cluster size of 3 in linear cells, and the mobile at a distance of 0.5 R_c, the SIR is 12.189 dB in free space when the path loss exponent is (γ =2), 19.619dB for (γ =3), and 26.954dB for the urban area where (γ =4). For the same cluster size in the hexagonal cell, and at the same location (x=0.5 R_c), the SIR is less than 2.0dB in free space, 13 dB for (γ =3), and about 17 dB where (γ =4). The SIR at the mobile unit located at the cell center in hexagonal cells is less than that of linear for the same cluster size due to the higher number of interfering cells in the case of hexagonal topology. Simulation shows that when the value of the path loss exponent increases, the value of SIR increases exponentially for both linear and hexagonal topologies. This occurs due to higher attenuation of the interfering signals with higher path loss exponent.

Figure 7 compares the SIR for both hexagonal and linear cells systems at different path loss exponent values. For cluster size (N=7), SIR is equal to 20 dB in linear cells, while it was calculated to be 5dB in hexagonal cells. The reason beyond that is the number of interfering cells in linear systems is less than that of hexagonal networks. The figure also shows that in both systems, the SIR is greater in environments of higher path loss exponent value.

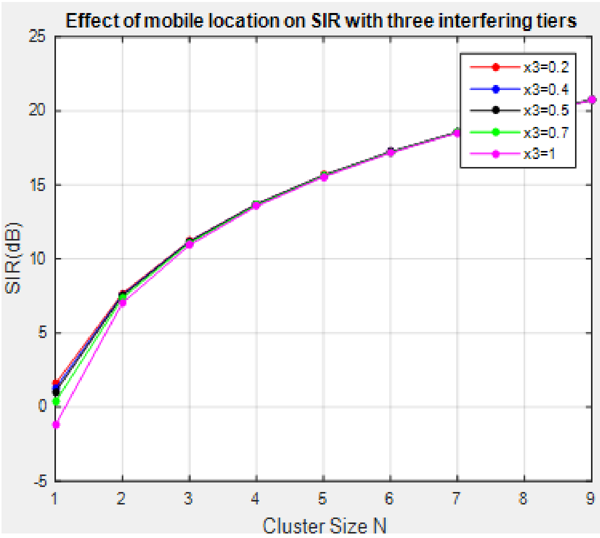

FIGURE 5. Effect of multi tiers on SIR

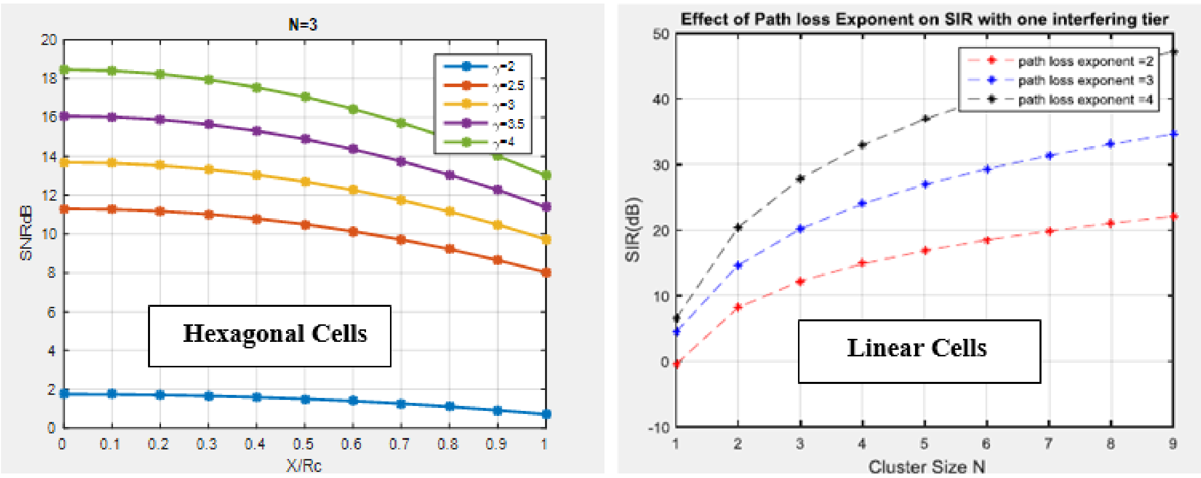

FIGURE 6. Effect of path loss exponent on SIR

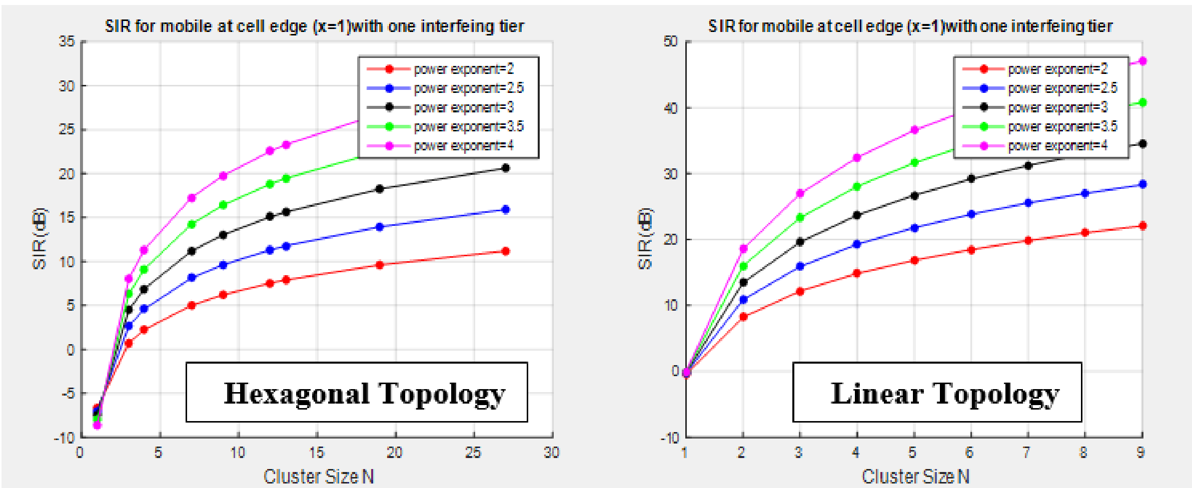

FIGURE 7. SIR For Hexagonal and Liner Cells

5. CONCLUSIONS

In this paper, the effect of other-cells interference on SIR received by mobile station value has been investigated through the simulation of a mathematical model. Simulation has been done considering one, two, and three tiers of surrounding interfering cells and for both hexagonal and one-dimensional cell scenarios. The work has investigated the effect of path loss exponent value on SIR in various environments. Simulation shows that in both hexagonal and linear cells pattern, as the value of path loss exponent increases, the value of SIR increases. The result clearly indicates that there is a significant effect of multi-tiers on SIR value in the case of clusters of small size, and this effect can be neglected for systems of large cluster size.

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CONFLICTS OF INTEREST

The author declares no conflict of interest.

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